Low Energy Program Overview

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Introduction

The low-energy nuclear physics program focuses on the study of nuclear properties under extreme conditions and uses nuclei as a quantum system to test fundamental symmetries and to understand the weak interaction. Most of the studies use beams provided by the 88-Inch Cyclotron to produce nuclei with high angular momentum, large deformations, high temperature, an excess numbers of neutron or protons as well as new super-heavy elements. State-of-the-art instrumentation developed at LBNL was used for these experiments. Gammasphere is in full operation, after returning from ANL, and a broad physics program was started in July involving a large user community. The Berkeley Gas-Filled Separator (BGS) provided the capability to discover the new super-heavy elements 118 and 116; a major breakthrough in the quest for an island of super-heavy nuclei. Significant progress has been made in facilities for weak interaction studies. These include a magneto-optical atom trap and a 14O source; both provided important results for precision beta-decay measurements. The development of a Gamma Ray Energy Tracking Array (GRETA) has achieved many milestones, including determination of the position resolution in three dimensions and the tracking of pair-production events. The new radioactive beam capability (BEARS) provided a beam of ^{11}C which was used in several experiments with world record intensity and energy for this beam. Additional exotic beams such as ^{14}O are being developed

Nuclear Structure

The nuclear structure group studies the complex many-body properties of nuclei (sometimes referred to as emergent properties) in terms of the elementary modes of excitation: rotations, vibrations, single-particle, pairing, etc. By subjecting the nucleus to extreme conditions, encountered, for example, at high angular momentum and diverse proton to neutron ratios, the subsequent gamma-ray decays (observed in multi-Ge detector arrays, e.g. Gammasphere) can be used to isolate and study the various phenomena that emerge. The group's research has focused on two areas; nuclei far from the beta-stability line and nuclei at high spins. The outstanding question for N=Z nuclei has been whether they can sustain a new form of pairing condensate comprising of np pairs (deuteron-like) coupled to isospin T=0. Normal paring contains T=1 pairs. Experimental results on ^{72}Kr indicate a delayed alignment, which has been interpreted as an effect of both T=1 and T=0 np-pairing correlations at high spins. Several studies of superdeformed states were carried out. The lifetimes of the superdeformed states in the N=Z nucleus ^{36}Ar were measured and the quadrupole transition matrix elements were deduced for each state. The data provide a detailed comparison with spherical shell model calculations, and information on the microscopic origin of nuclear collective rotations, and the evolution of collectivity as a function of angular momentum up to the terminating state. Notable highlights from the high-spin studies include; (i) A successful search for the predicted superdeformed structures around A~110: a high-spin (40-60 h) collective band was found in ^{108}Cd and lifetime measurements yield a lower limit for the deformation corresponding to a 2:1 axis ratio, (ii) Analysis of the continuum spectrum revealed a large increase in the moment of inertia with increasing spin (above ~30 h) for nuclei with A<140,as predicted by W.Swiatecki and W.Myers. These results are consistent with prediction but occur at appreciably lower spin than initial calculations and it is difficult to exclude other effects such as individual nucleon alignments, and (iii) the continuum gamma-ray spectrum of $^{166\text{-}168}$Yb was studied. A quantitative understanding of its structure has been obtained through comparison with simulations. Reliable values of the rotational damping width can now be extracted. These studies mark an important advance in obtaining an empirical measure of the transition from well-defined (ordered) rotational motion to regions of mixed (chaotic) behavior.

In collaboration with the Argonne group, the move of Gammasphere back to LBNL began March 15th, 2000, and the installation of the array in cave 4C was completed in mid-July. Utilizing the down time during the move, we have implemented a new constant-fraction discriminator, which provided a factor of 4-5 improvements in the gamma-ray detection efficiency at 60 keV. The security, reliability, and speed of the computer network were improved by the installation of a firewall and the upgrade of the network hubs. Several upgrades are in progress. They are (i) extending the trigger time to 2 msec, (ii) development of a new data-acquisition system to improve the data throughput and overall reliability using a more powerful VME-based Power PC and initial tests demonstrated its feasibility, and (iii) provide DLT tape drives for data recording, with conversion facilities to allow users to continue use 8 mm Exabyte tapes.

GRETA (Gamma-Ray energy Tracking Array) is a new concept in gamma-ray detector arrays based on highly segmented Ge detectors, and has the potential of providing 100 to 1000 times the sensitivity of Gammasphere. This year the research and development effort has achieved several important milestones. Further measurements were carried out on the prototype detector with
36-fold segmentation. Detailed measurements of the crystal-orientation dependence of the charge drift direction and velocity in the detector have been performed. The signals were analyzed on an event-by-event basis. In this way, position resolution limiting effects such as the range of Compton electrons, crystal orientation, and the alignment of the Ge crystal are taken into account. A three-dimensional position resolution of 0.5-0.9 mm at gamma-ray energy of 374 keV was measured. This is better than what is needed for accurate gamma-ray tracking. Several algorithms have been developed for decomposing signals composed of multiple interactions. These studies indicate that an algorithm with sufficient accuracy and speed could be developed for online data processing. Other areas of R&D carried out this year included algorithms for timing determination and tracking of pair-production events. A national GRETA steering committee was established and is consulted regularly for advice on planning and community participation of the R/D efforts.

Nuclear Reactions

The nuclear reaction group studies the physics of the emission of complex fragments, from its onset as binary compound nucleus decay to its full deployment as multifragmentation. It has been a rich source of new experimental and theoretical understanding in terms of thermo physics of nuclei as mesoscopic clusters and of the process of liquid-vapor equilibrium. Two properties; reducibility (the many-particle emission probability reduces to a one-particle probability), and thermal scaling (the one-particle probability scales like a Boltzmann factor), have been demonstrated to be features of a model describing the condensation of droplets from a vapor near its critical point (Fisher's droplet model). This observation has prompted a new analysis, which has yielded a deeper insight into the mechanism behind multifragmentation. When applied to the EOS 1 AGeV Au+C multifragmentation data set, the cluster properties follow the Fisher model prediction along the coexistence line, all the way to the critical point, thus providing the best evidence for liquid-vapor coexistence. Beyond hyperdeformation, the fission saddle point shape is the largest deformation a nucleus can sustain. To study the saddle point properties, a novel technique to measure precision fission barriers has been developed and applied to long chain of Pb, Bi and Po isotopes. The fission barriers were determined with near spectroscopic precision. In addition, ground state shell effects, the surface dependence of the level density parameter, and the pairing strength at the saddle were studied in these isotopes. A new technique was developed for extracting the fission time delay directly from cumulative fission probabilities of neighboring Os isotopes. This work gives a most probable value for the delay time of 10-20 sec.

BEARS

BEARS, Berkeley Experiments with Accelerated Radioactive Species, uses two cyclotrons to produce radioactive beams. The radioactive nuclei are produced at the medical cyclotron in building 56 and are transferred in gaseous form to building 88 through a 350-meter transfer line. The cryogenic trapping of the activity, the separation of the carrier gas, and the injection into the AECR source are controlled automatically. A continuous ^{11}C beam with intensity up to 2 x 108 ions/s at energy up to 125 MeV was produced for several experiments and represents the highest intensity and energy achieved for an 11C beam. Current efforts are focused on the development of a ^{14}O beam. Several loss mechanisms of ^{14}O, such as reaction with the wall of the target chamber, were identified and eliminated. In the current approach, the ^{14}O is produced in the chemical form of water and then converted to CO2 before it is transported to 88-Inch cyclotron. A beam intensity of 1 x 106 ions/s is projected. Other beams, such as ^{13}N, ^{15}O, ^{17}F,and ^{18}F, are planned. In the study of proton-rich nuclei, two new nuclei ^{178}Tl and ^{178}Pb were identified by alpha decay at the focal point of BGS.

Weak Interactions

The weak interactions group performs precision studies of weak interaction parameters in the search for physics beyond the standard model. The unique capability of the 88-Inch cyclotron to provide high-intensity light-ion beams is essential for the production of the exotic nuclei for these studies. Significant progress was made this year on the experiment to measure the electron-neutrino angular correlation in the beta decay of laser-trapped 21Na atoms. This measurement will set a limit on possible scalar and tensor contributions to the electroweak currents. At present, the measurements have reached a statistical precision of a few percent. Additional measurements and detector improvements are planned, and they will result in a more stringent limit. A new ECR source was installed to ionize radioactive ^{14}O produced by a ^{3}He beam from the 88-Inch Cyclotron on a 12C target. It has provided a world record beam current of 2 x 10^7 ions per second. The experimental program with this system has begun with a precision measurement of the ^{14}O lifetime, to be followed by a beta spectrum shape factor measurement to test the Conserved Vector Current hypothesis, and a determination of the 0^+ to 0^+ branching ratio. A proof of principle run to search for the charge conjugation violating four-photon decay of para positronium was carried out successfully using Gammasphere. Measurements on the forbidden magnetic dipole transition in Yb are nearly completed, and work has begun on an apparatus to measure P-non-conservation in Yb.

Heavy Element Nuclear Chemistry

Following the successful production of element 118 and its daughter element 116, the heavy element group attempted to confirm this results and to measure the excitation of the ^{86}Kr + ^{208}Pb reaction. These experiments failed to observe additional events due to an unexpected shift in the position of the evaporation residues (EVRs) at the BGS detector. The shift in EVR positions is now understood to be due to two causes. The first was a reduced magnetic field in one of the BGS dipole magnets (from installation of a noise filter in the magnet power supply). The second seems to be from an impurity in the BGS fill gas during some of the experiments. After these experiments, a large effort was made to gain a better understanding of the BGS operation and several improvements were made. Magnetic rigidities and efficiencies were measured for a number of reactions producing EVRs with Z=100, 102, 104, 105, and 110. These results provided a better understanding of the systematics of the average charge state of EVRs in helium gas. Also, the BGS efficiencies can now be reproduced by an improved computer code. The experiment to confirm the 118 results will be carried out during April-May 2001. Several experiments have been performed to study the chemical properties of the heaviest elements. The decay properties of ^{266}Bh and ^{267}Bh were determined at both the 88-Inch Cyclotron, and at the PSI Phillips cyclotron. The ^{267}Bh isotope was used to make the first measurements of the chemical properties of element 107. A Recoil Transfer Chamber has been built which allows the EVRs from BGS to pass through a thin window and then transported via a gas jet to the chemical separation system. The chemistry experiments carried so far were a test of a system to measure the volatility of hassium (108) compounds (using the osmium homolog), and the first successful transactinide experiments with the SISAK continuous liquid-liquid extraction system.